Production of high yield bleached hardwood kraft pulp: Breaking the kraft pulp yield barrier

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ABSTRACT: A modified kraft pulping process has been developed that successfully breaks the traditional hardwood kraft pulp yield barrier. The process produces fully bleached, high brightness hardwood kraft pulp with a yield of greater than 53% on wood. Details of the development and processing steps, along with various recovery cycle impacts, are discussed.

Application: By improving the pulp yield, mills will require fewer trees to manufacture the same amount of paper and, with this new process, can reduce operating costs.

Wood pulping traditionally has been divided into two main categories: mechanical pulping methods and chemical pulping methods [1]. Mechanical pulping primarily uses mechanical energy to separate fiber from wood without a substantial removal of lignin. Mechanical pulps traditionally are associated with high yields of greater than 80% on ovendry (o.d.) wood, relatively low strength properties, and high energy requirements [2]. Chemical pulping uses chemical and thermal energy to liberate pulp fibers from wood by dissolving substantial portions of lignin from the wood. Chemical pulps traditionally are associated with relatively low pulp yields of around 50% or less on o.d. wood, high strength properties, and relatively low amounts of energy input [3].

Over the years, several processing changes have been made in mechanical pulping systems to improve pulp strength while maintaining yield and reducing the amount of required mechanical energy. Thermomechanical pulping (TMP) grinds wood chips into pulp under steam at elevated pressures and temperatures [4,5]. Chemithermomechanical pulping (CTMP) uses chemicals prior to or in situ with a mechanical pulping stage. CTMP has somewhat lower yield (75%-85% on o.d. wood) than mechanical pulping, but it provides pulp fibers with a slightly improved strength [6,7]. Sodium sulfite has been the main chemical used for CTMP [8]. Within the past 10 years or so, the industry has begun to use hydrogen peroxide in conjunction with caustic as an impregnation chemical and as a chemical directly applied to a high consistency refiner treatment for CTMP [9]. This pulping process, known as alkaline peroxide mechanical pulping (APMP), provides fiber pulps with enhanced brightness and improved strength compared to traditional CTMP methods. Additionally, recent breakthroughs in the APMP process have been associated with a reduction of the required refining energy through an application of a secondary, low consistency refining system and an enhancement of barrier screening technology to selectively retain rejects while allowing the desirable fibers to pass through to a paper machine [10]. Substantial energy reductions have also been noted in APMP processes through selective impregnation of enzymes into the wood chips prior to refining [11-13].

Chemical pulping is organized into four major categories based on the chemicals used in each process. These categories are kraft, soda, carbonate, and sulfite pulping [1]. Alkaline pulping (AP) uses an alkaline solution of sodium hydroxide with sodium sulfide (kraft process) or without sodium sulfide (soda process). Carbonate or green liquor cooking uses either sodium carbonate and caustic or green liquor, with some caustic under slightly alkaline cooking conditions to produce high yield medium type pulps. Acid pulping uses an acidic sulfite solution (sulfite process). Compared with mechanical pulping, chemical pulping provides pulp fibers with improved strength because of a lesser degree of fiber degradation and enhanced bleachability through lignin removal. Worldwide, the currently predominate chemical pulping process is the kraft process [14]. One major problem with the kraft process is the relatively low pulp yield of around 50% or less on o.d. wood. Under some very specialized conditions such as cooking 100% aspen, a higher yield of up to 54% may be obtained, but the typical kraft process generally produces a yield of around 50% or less on o.d. wood.

Significant research has been expended over recent years to improve the apparent "kraft pulp yield barrier" while maintaining chemical pulp performance characteristics such as high strength. During 2004-2007, the U.S. Department of Energy's Agenda 2020 program sponsored several research projects to achieve this manufacturing breakthrough endeavor. In 2006, the Agenda 2020 Technology Alliance, American

Forest and Products Association (AF&PA), and the U.S. Department of Energy jointly published a technology roadmap for the forest products industry that defined one of the performance goals for breakthrough manufacturing technologies as producing equivalent or better fiber at 5% to 10% higher yield. Target pulp yield increases of 5%-10% are considered to be revolutionary to the pulp producing industry [15]. To date, the Agenda 2020-funded projects have achieved, at best, a 2%-4% pulp yield increase. These developed technologies include a double oxygen treatment of high kappa pulps, a use of green liquor pretreatment prior to pulping, and a modification of pulping chemicals and additives used for pulping. However, all of these attempts to achieve a breakthrough of 5%-10% yield increase have failed [15]. Other known chemical pulping modifications to increase pulp yield include a use of digester additives such as anthraquinone, polysulfide, penetrant, or various combinations of these materials [16]. Again, in all instances, only a 1%-5% brownstock yield increase over a traditional kraft pulping process has been realized. Additionally, these modified chemical pulping processes often provide pulps with lower tear strength.

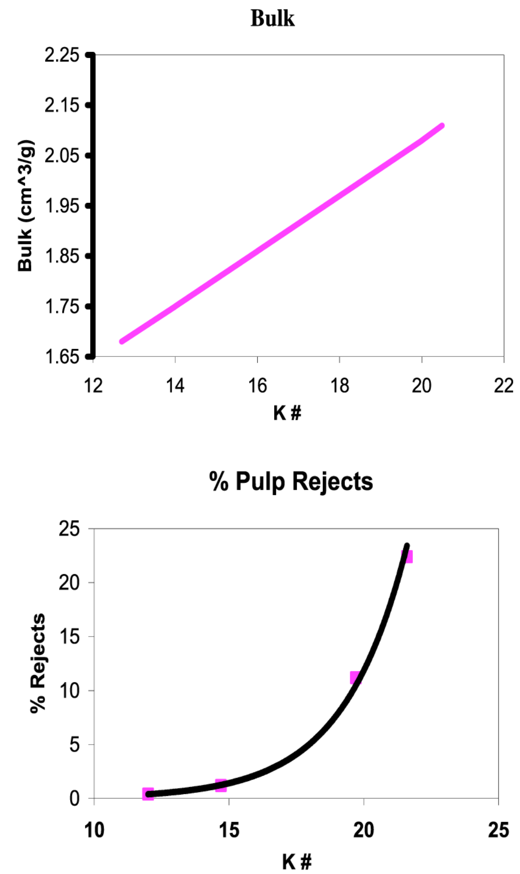
DEVELOPMENT OF THE HIGH YIELD PULPING PROCESS

For this work, each step of the kraft pulping process was examined, from the digester operating conditions and operational targets through knotting, screening, washing, and bleaching, with the goal of producing a final bleached pulp with an increased stiffness at a given bulk and a breakthrough yield. A secondary goal was to ensure that the new process did not sacrifice the optical and strength properties associated with bleached kraft pulp. A third major requirement of the new process was that its environmental impact had to be maintained at current or lower kraft pulping and bleaching levels [17,18].

Pulping targets

Kraft pulping typically has been divided into two major end uses: unbleached pulps and bleachable grade pulps. The new process may be applied to both bleached and unbleached fiber, but the current work will focus only on bleachable grade pulp.

For hardwood kraft pulps, increased bulk may be obtained by simply increasing the target kappa number of the brownstock pulp (**Fig. 1**). As shown in **Fig. 2**, increased total unbleached pulp yield also results from increased kappa number targets. Unfortunately, as the kappa number of the pulp is increased to obtain this enhanced bulk and increased total yield, the amount of shives or screening rejects (Fig. 1) in the resulting pulp also increases [19]. Pulp bleaching costs also tend to rapidly increase with increasing brownstock kappa numbers [20]. To minimize shive formation and maintain low bleaching costs, bleachable grade hardwood kraft pulping typically is carried out to a kappa number of less than 20, which generates about 1-3 weight % of undercooked fiber bundles and about 97-99 weight % of liberated pulp fibers. The undercooked,

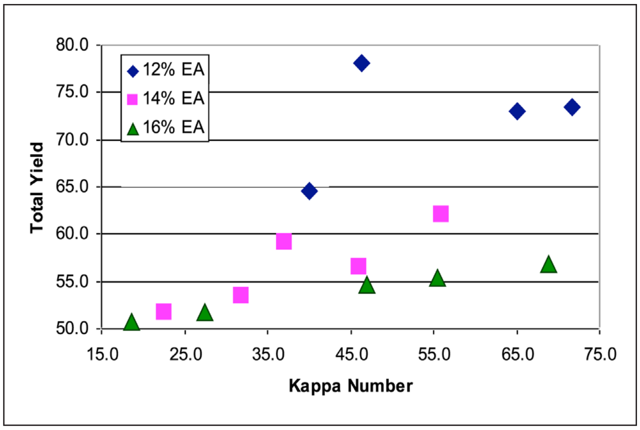


1. Impact of brownstock kappa number on the bulk and reject production during hardwood kraft pulping.

nonfiberized materials are commonly known as rejects, and the liberated fibrous materials are known as accepts pulp. Rejects are separated from accepts pulp by a multiple stage screening process. Rejects usually are disposed of in a sewer, recycled back to the digester, or thickened and burned. When the rejects are recooked in the digester, they tend to exhibit an extremely low fiber yield, an increase in the level of pulp dirt, and a decrease in pulp brightness (poorer bleachability) [21].

Screen room

Modern screen rooms typically are designed to remove about 1-3 weight % of rejects from a chemical pulping process [3]. If a mill experiences cooking difficulties and accidentally undercooks the pulp, the amount of rejects increases exponentially. Modern bleachable grade kraft pulp screen rooms are not physically designed to process pulps with more than about 5% by weight of rejects. When the level of rejects increases to slightly more than 4%-5% by weight, either the screen room plugs up and shuts down the pulp mill or the screen room is bypassed and the pulp is dumped onto the ground or into an off quality tank and disposed of or gradually blended back into the process. Therefore, bleachable grade kraft pulps are conventionally cooked to relatively low kappa numbers of 12–20 for hardwoods



2. Impact of kappa number on total pulp yield at various applied effective alkali (EA) cooking conditions.

3. Bleaching costs for various sequences starting with a high kappa number pulp relative to a D EP D D bleach sequence for an 18 kappa hardwood pulp.

to maintain a low level of rejects and good bleachability.

This study showed that the overall brown pulp yield could be increased substantially if the kappa number of the pulp coming out of the digester also was increased (Fig. 2). Consequently, we decided to break the existing mill paradigm of pulping to a low kappa number to reduce rejects. We decided to substantially increase the total pulp yield by purposefully pulping to fairly high kappa numbers of 40-60. By doing this, we tended to create 25%-40% rejects in the brownstock fiber coming from the digester. Unfortunately, the amount of rejects associated with that increased yield actually lowered the yield of usable screened fiber obtained from the cook to less than conventional levels (Fig. 1). To successfully enhance the resulting usable pulp yield, some method was needed to convert the rejects into usable pulp fiber.

When these rejects were repulped, the yield on rejects sharply decreased, as did usable pulp yield. Repulped rejects produced a usable pulp yield of 30%-35% on rejects charged to the system. Therefore, borrowing from mechanical pulping technology, the rejects obtained from the high kappa pulp were fibrillated with a high consistency refiner. The refined rejects obtained from the high consistency refiner were then passed through a two stage screening process with two primary screens in series. The accepted fiber obtained from this screening process was recombined with the primary accepts from the first screening and sent forward to bleaching. The rejects from the refiner screen room were sent back to the reject refiner until they were converted into accepts via mechanical action.

Bleaching and effluent targets

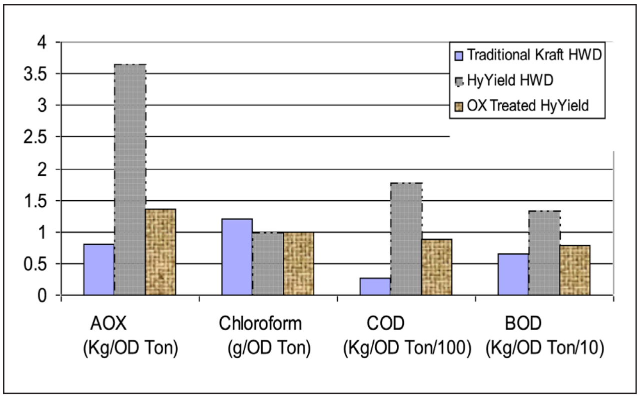
Some mills have used reject refining in an effort to enhance pulp yield. Unfortunately for bleachable grade pulps, the refined rejects have resisted bleaching, thus causing increased amounts of undesirable dirt and specks in the bleached pulp. Higher bleaching costs also have been associated with this practice.

In an effort to render the refined rejects more susceptible to bleaching, an alkaline peroxide solution was applied directly into the high consistency reject refiner during the refiner operation. The use of alkaline peroxide improved the fiber quality, decreased the amount of refined rejects, and rendered the resulting acceptable fiber more susceptible to chemical bleaching methods.

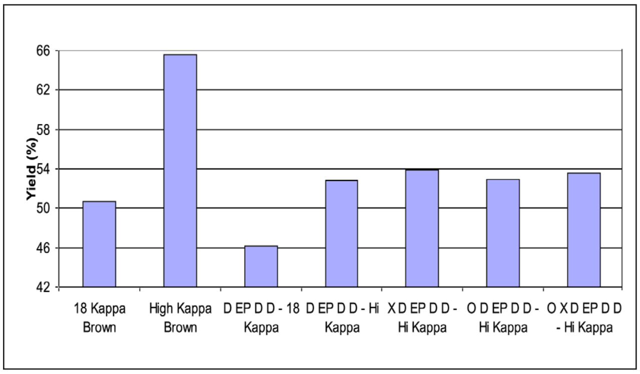
In addition to enhancing fiber liberation (decreasing rejects), mills frequently have pulped to lower kappa numbers to decrease the cost of bleaching. When a traditional D EP D D bleaching sequence was used to a constant 88 GE brightness for the current high yield fiber, the relative bleaching cost was 1.66 times that of a control 18 kappa fiber obtained from the same wood mix. Various combinations of oxygen and enzyme bleaching conditions were combined with the standard D EP D D bleaching sequence in an effort to lower the resulting bleaching cost associated with bleaching the high kappa combined fiber prepared in the manner stated previously. **Figure 3** shows the resulting relative bleaching costs for the various bleaching sequences.

Another problem associated with the traditional bleaching method was the release of undesirable materials into the mill effluent. Adsorbable organic halogens (AOX), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and color were drastically increased when the high kappa brownstock pulp was bleached as compared to the amount of these materials found in 12-18 kappa brownstock bleaching. **Figure 4** shows the environmental performance of the new process effluent versus the effluent of a traditional kraft pulp when both fibers are bleached to 88 GE brightness in a D EP D D bleaching sequence.

Obviously, the dramatic increase in effluent emissions and the substantial cost increase had to be overcome through enhanced bleaching methods. After evaluating several different candidate bleaching processes, we decided to focus on an O X D EP D D bleaching sequence for the current work. The X is a designation for a xylanase enzyme bleaching stage. When this bleaching sequence was used, the bleach plant chemical cost was reduced slightly as compared with an 18 kappa traditional sequence pulp and the bleach effluent pollution load was reduced substantially compared with the traditional bleaching sequence with a high yield pulp.



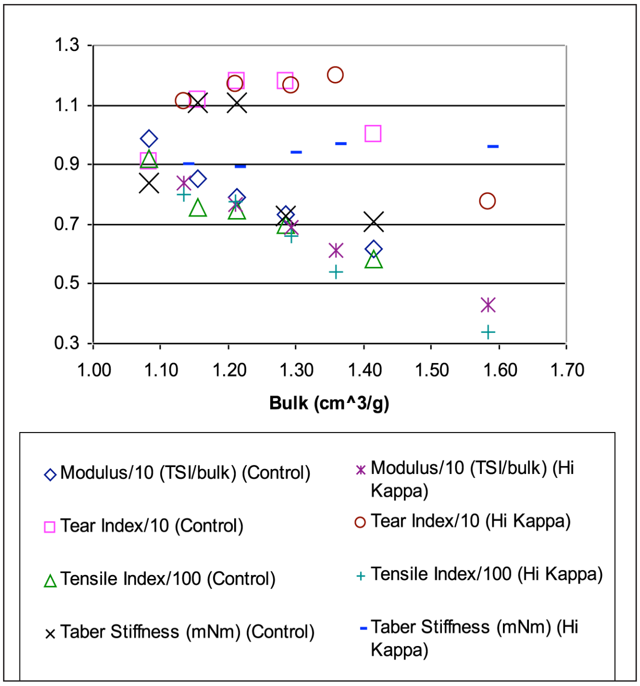
4. Environmental performance of high-yield hardwood pulp bleaching effluent compared to traditional kraft pulp when bleached with a D EP D D bleaching sequence and with an O X D EP D D sequence to 88 GE brightness.



5. Yield for the 18 kappa and high kappa brownstocks and for the fully bleached 18 kappa and high kappa pulp bleaching sequences. All bleaching sequences were to 88 GE brightness.

Yield

When pulping mixed southern hardwoods to a traditional kappa number of about 16-18, the resulting brownstock pulp yield is about 50%-51% on o.d. wood. By targeting a 55-60 kappa number, the resulting brownstock yield increases to around 65% on o.d. wood. Unfortunately, a significant amount of the increased yield is in the form of lignin. This lignin is removed during the bleaching process and converted to AOX, COD, and BOD in the resulting bleach plant effluent. When bleaching an 18 kappa brownstock pulp with a traditional D EP D D bleaching sequence, the resulting fully bleached yield is about 46%, representing a 4-5 point shrinkage across the bleach plant. When the high kappa fiber with treated rejects was subjected to standard D EP D D bleaching sequence to full brightness, the resulting bleach plant shrinkage was found to be roughly 13 points for a fully bleached yield of about 53% on o.d. wood. Even though the shrinkage was considerably greater for the high kappa fiber, the overall yield was still considerably higher than the yield for the conventional fiber. In fact, the overall bleached yield increase was in the designated "break through" range described by the Agenda 2020 study [15]. **Figure 5** shows the yield for each of the bleaching sequences discussed.



6. Physical property testing results for the 18 kappa bleached control fiber and for the high yield oxygen-enzyme bleached fiber.

The highest fully bleached yield of more than 53.5% was obtained for the combined oxygen-enzyme bleaching sequence, which resulted in the lowest bleaching cost.

Physical properties

Each of the fibers, both bleached 18 kappa control and bleached high kappa, high yield pulp were refined in a Pro-Lab refiner (Metso Paper; Helsinki, Finland). Samples were collected at a no load condition and four different levels of refining energy, and then made into 125 g/m^2 handsheets. The refining energy conditions were 0.75, 1.5, 2.25, and 3.0 horsepower days/ton (HPD/T). The no load condition corresponded to 0.05 HPD/T. Each of these handsheets were subjected to standard physical testing. **Figure 6** shows the results of the tensile index, tear index, modulus, and Taber stiffness for the 18 kappa bleached control and the oxygen-enzyme bleached high yield bleached fiber. As seen in Fig. 6, similar physical properties were obtained for both the control and the high yield fiber.

CONCLUSIONS

Breaking the paradigm of pulping to a kappa number below the fiber liberation point (about 20 for hardwood) and purposefully creating a high shive content fiber, a high yield fiber was obtained. The resulting high shive content (30%-35% shives) fiber requires segregating the accepts and rejects in the screen room and further treating of the rejects. Reject treatment consists of thickening the rejects stream to 25%-35% consistency, followed by high consistency refining with the addition of alkaline peroxide into the high consistency refiner. These refined rejects are screened with the resulting refiner rejects being recombined with the primary screen room rejects and the refined accepts being combined with the primary screen room accepts. The resulting combined accepts are then washed and bleached in an O X D EP D D bleaching sequence to high brightness.

Compared with a fully bleached, 18 kappa hardwood pulp, the resulting bleached pulp has a significant increase in final bleached yield of at least 7 points (Fig. 5). The bleaching costs are slightly lower for the high yield pulp than for the 18 kappa pulp (Fig. 3). The physical properties of the two fibers are similar to each other (Fig. 6). The resulting bleach plant effluent properties were increased for the high yield fiber. The amount of increase was substantially dependent upon the bleaching sequence employed. The AOX, BOD, chloroform, COD, and color for the oxygen enzyme treated fiber were not above the levels mandated by the Cluster Rules.

In general, the resulting fiber successfully retained a significant portion of the enhanced brownstock yield, and the resulting yield increase was determined to be at breakthrough levels. **TJ**

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LITERATURE CITED

1. Smook, G.A., *Handbook for Pulp & Paper Technologists*, 2nd edn., Angus Wilde Publications, Bellingham, WA, USA, 1992.
2. Kocurek, M.J., series Ed., and Leask, R.A., Tech. Ed., Pulp and Paper Manufacture, Vol. 2, *Mechanical Pulping*, 3rd edn., The Joint Textbook Committee of the Paper Industry, TAPPI/CPPA, Atlanta, GA, USA, 1996.
3. Kocurek, M.J., series Ed., Grace, T.M., Malcolm, E.W., Tech. Eds., Pulp and Paper Manufacture, Vol. 5, *Alkaline Pulping*, 3rd edn., The Joint Textbook Committee of the Paper Industry, TAPPI/CPPA, Atlanta, 1996.
4. Leask, R.A., *Pulp Pap. Can.* 86(3): 20(1985).
5. Huusari, E. and Syrjanen, A., *Pulp Pap. Can.* 81(3): 32(1980).
6. Giertz, H.W., *Int. Mech. Pulping Conf., Proc.*, EUCEPA, Paris, France, 1977, p. 510.
7. Hoglund, H. and Bodin, O., *Sven. Papperstidn.* 79(11): 343(1976).
8. Constantino, J., Fisher, D., Joyce, P., et al., *TAPPI Int. Mech. Pulping Conf., Proc.*, TAPPI PRESS, Atlanta, 1983, p. 249.
9. Cort, C.J. and Bohn, W.L., *Tappi J.* 74(6): 79(1991).
10. Xu, E.C., *Annu. Meet. Prepr. - Pulp Pap. Tech. Assoc. Can., 89th*, PAPTAC, Montreal, QC, Canada, 2003, pp. 27-30.
11. Hart, P.W., Waite, D.M., Thibault, L., et al., *Holzforschung* 63(4): 418(2009).
12. Li, K., Lei, X., Lu, L., et al., *Pulp Pap. Can.* 111(1): 28(2010).
13. Sabourin, M.J., and Hart, P.W., *Ind. Eng. Chem. Res.* 49(12): 5945(2010).
14. American Paper Institute, *Statistics of Paper, Paperboard, and Wood Pulp*, American Paper Institute, New York, 1984.
15. Agenda 2020 Technology Alliance, *Forest Products Industry Technology Roadmap*, Agenda 2020 Technology Alliance, American Forest & Paper Association, U.S. Department of Energy, Energetics Inc., 2006, pp. 23-31. Available on-line at www.agenda2020.org.
16. Goyal, G.C., Ed., *Anthraquinone Pulping: A TAPPI PRESS Anthology of Published Papers*, TAPPI PRESS, Atlanta, 1997.
17. Hart, P.W. and Waite, D.M., World Intellectual Property Organization, WO 2008/154073 A1 (Dec. 18, 2009).
18. Hart, P.W., Waite, D.M., and Nutter, D.E. Jr., World Intellectual Property Organization, WO 2008/153565 A1 (Dec. 18, 2008).
19. Magnotta, V., Kirkman A., Jameel H., et al., *Breaking Pulp Yield Barrier Symp.*, TAPPI PRESS, Atlanta, 1998, p. 165.
20. Hart, P.W. and Connell, D., *TAPPI J.* 7(7): 3(2008).
21. Tikka, P., Tahkanen, H., and Kovasin, K., *Tappi J.* 76(3): 131(1993).

ABOUT THE AUTHORS

Hart

Several years ago, the U.S. Department of Energy, through Agenda 2020, published a research challenge to find a method of successfully breaking the perceived kraft pulp yield barrier. None of the researchers successfully obtained the stated goals. Darrell Waite and I attempted to develop a breakthrough technology that could successfully achieve this goal.

The current research successfully marries high-yield pulping practices with chemical pulping methods to obtain a low cost, high quality pulp fiber. Typically, the two fields of pulp manufacturing have been relatively isolated from each other, with mechanical pulping experts focusing on high-yield fiber and kraft experts focusing on chemical pulps. The current work successfully draws from both sides to make an improved yield chemical fiber with good strength properties

Deciding to break the chemical pulping paradigm of low rejects was difficult. Determining how to bleach the fiber economically and with minimal cost and environmental impact was a major challenge. As we conducted our research, it was surprising to see the impact that enzymes had on bleaching the high kappa number fiber.

By improving the pulp yield, mills will require fewer trees to manufacture the same amount of paper. This technology is an excellent operating cost reduction and sustainability method for the industry. The next step is full-scale implementation in the mill.

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